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Macroeconomic Drivers of Singapore Private Residential Prices: A Markov-Switching Approach

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Abstract: This paper attempts to address the relationship between various macroeconomic variables affecting Singapore private residential prices using a Markov-Switching approach rather than a single state linear regression framework. We adopt the 3-regime approach used by Nneji *et al.* (2013). The dataset encompasses a period from 1978Q1 to 2012Q1. Based on the extant literature, various macroeconomic variables that affect house prices were chosen. They are inflation rates, exchange rate changes, real interest rate changes, population growth, changes in public housing supply, and growth in real disposable income. The results indicate that in the steady and boom state, inflation rates, population growth, disposable income growth, and public housing supply changes are significant in explaining growth in private residential prices. Several abnormal results are also documented namely the non-significance of interest rate changes. Using a Markov-switching approach provides added information in identifying significant variables in each state allowing government policymakers to be more specific in using proper policy measures when addressing private residential price growth.

Keywords: Private residential property prices, Markov-Switching Model, macroeconomic drivers, Singapore, Regime-Switching, real estate.
JEL classification: E32, G12, R31

1. Introduction

The residential property market is one of the linchpins of the Singapore economy, with high property prices arising as one of the key issues during the General Election in 2011. The ratio of housing investment to gross domestic product (GDP) has averaged 7 percent from 1960 to 2013, with housing investment to total investment ratio averaging at 23 percent. These ratios are high by international standards and emphasizes active intervention by the Singapore government in the residential property market (Phang and Helbe, 2016). Internationally, real estate activities account between five per cent to ten per cent of GDP (Hilbers *et al.*, 2001). A residential property is considered to be the largest single asset households own in a portfolio of assets in terms of value. It is also a significant contributor towards the bottom line of financial intermediaries (Tsatsaronis and Zhu, 2004). For example, prior to the Asian Financial Crisis in 1997, real estate loans as a percentage of total Singapore bank loans averaged 30-40 per cent (Koh *et al.*, 2005).

The residential property market in Singapore is unique as it is a 2-tier system consisting of a public housing market administered by the Housing Development Board (HDB) on behalf of the Singapore government, and a private housing market. Although the public housing market accommodates 80 per cent of the total number of households as of year 2015, private sector investment in the private housing market has been growing steadily. As

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of 2009, 21.7% of the total housing stock has been built by the private sector (Renaud *et al.*, 2016).

The cyclical nature of real estate prices has been well documented in developed countries (see Saito (2003) for a review for U.S. and Japan). However, in recent times, this cyclical nature has been exacerbated by the increased volatility of prices due to various external shocks such as the 1997 Asian financial crisis, the bursting of the U.S. dot.com bubble in 2001 followed by the SARS epidemic of 2003 and eventually the 2007-2008 Global Financial Crisis (Renaud *et al.*, 2016). This phenomenon is now considered a threat towards global prosperity not seen since the Great Depression (Lougani, 2010). This global phenomenon is also observed in Singapore private housing prices, with six major boom and bust cycles identified from the private residential property price index (PPI) published by the Urban Redevelopment Authority (URA)[1]. Whilst the duration between the peak and trough of a cycle has shortened, the frequency of residential property cycles has exacerbated (Schwarz, 2012).

The cyclical duration of the private housing market prices has become a major concern with each successive cycle in developed and developing countries. The U.S. real estate market, for example, experienced one of the longest booms in history where real housing-price appreciation averaged 5.5% on an annualised basis from 1997-2002 and 9.6% from mid-2002 to the first quarter of 2006. Real growth peaked at 12.1% in the second quarter of 2005. Prices collapsed thereafter and between mid-2005 to end of 2008, annual real housing-price growth averaged -9.1% (Dymski, 2010). The downturn precipitated the near collapse of the U.S. financial system culminating with the bankruptcy of Lehman Brothers and the nationalisation of Freddie Mac and Fannie Mae.

Given that housing wealth is a primary contributor to total wealth, the argument follows that a downturn in the housing market would result in a decline in household consumption levels, subsequently resulting in a slowdown of economic growth which may trigger an economic depression (Nneji *et al.*, 2013). These property cycles also jeopardize the stability of financial intermediaries, especially during bubble periods, due to excessive risky lending (Koetter and Poghosyan, 2010). Property cycles constitute a serious concern within the context of South-East Asia as the extant literature has shown that the bottom line of financial intermediaries have been affected by movement in real estate prices (Inoguchi, 2011).

The discussion above highlights the importance for the Singapore government to be prudent in managing these cycles by developing a thorough understanding of the drivers of residential prices during the various stages of the cycles in order to implement informed and effective policies. As such, the objective of this paper is to determine the macroeconomic variables that influence the private housing prices at various stages of a property cycle, with the stages of a property cycle defined to be a “boom”, “steady state” or “crash” state/regime. This analysis is done using a three-regime Markov switching framework. This methodology allows for the relationship between the macroeconomic drivers and the private housing prices to be regime-varying, thus providing a rich vein of information pertaining to how selected macroeconomic variables interact differently with private housing prices at different stages of a property cycle.

This framework diverges from the current bulk of literature which often assumes that the relationship between private housing prices and macroeconomic variables exhibit stable properties and are consistent through time (Adams and Füss, 2010; Baffoe-Bonnie, 1998; Bardhan *et al.*, 2003; Bouchouicha and Ftiti, 2012; Brooks and Tsolacos, 1999; Case *et al.*,

[1] Among the cyclical periods identified were 1974-1986, 1986-1988, the 1997 Asian Financial crisis, the 2003 SARS Epidemic and more recently the 2008 global economic downturn.

2000; Edelstein and Lum, 2004; Ho and Cuervo, 1999; Muellbauer and Murphy, 2008; Ng, 2002; Peng, 2002; Peng *et al.*, 2008; Tsatsaronis and Zhu, 2004; Tu, 2004). There is evidences that changes in private housing prices react differently to macroeconomic variables at different stages of the housing cycle (e.g. Hui, 2013; Xiao, 2007). Therefore, any resultant relationship between private housing prices and macroeconomic variables may distort the true nature of that relationship if this fact is ignored. As such, one of the approaches towards analysing empirical relationships between housing prices and macroeconomic variables is the inclusion of structural breaks in house prices that results from huge upswings and collapses in prices, as has been observed in countries around the world.

House price analysis accommodating structural breaks have been few and limited (exceptions are Xiao and Tan, 2006; Xiao, 2007; Nneji *et al.*, 2013). This paper contributes to the extant literature by exploiting regime-switching properties in the analysis of the macroeconomic variables that influence private residential prices in the Singapore private housing market, allowing for the variables to behave differently in different stages of the housing cycle. The paper is organised as follows: Section 2 positions this study within the current strand of literature and briefly discusses the choices of macroeconomic variables used in the econometric model. Section 3 presents the descriptive statistics of the variables used in this paper. Section 4 presents the econometric model and explains in detail the Markov-switching methodology used to estimate the model. Section 5 focuses on the interpretation and discussion of the Markov-switching regressions results. We conclude the paper in Section 6.

2. Literature Review

Initial models on house price determination were focused on the real price of housing, rental costs in comparison with owning a property, and user costs, among other variables (Huang, 1966; Muth, 1960; Smith, 1969). Second generation models added expected capital gains and tax deductibility of interest payments as part of user costs (Buckley and Ermisch, 1982; Dougherty and Van Order, 1982; Kearl, 1979; Poterba *et al.*, 1991) and these models have become the mainstay in the empirical modelling of house prices. DiPasquale and Wheaton (1992) and Krainer (2002) further illustrated that house prices are determined by both demand and supply factors. Further advances in real estate price determination segregates the adjustment mechanism of house prices towards different macroeconomic variables based on a short term and a long term view. Madsen (2012) established that in the short run, house prices are driven by demand factors whereas in the long run, housing supply factors are the main underlying determinants. Van Order (1990) emphasised the need to look at both the short-term and long-term dynamics because policy tools that may be helpful in the short run may be counterproductive in the long run.

To a certain extent, researchers have reached a general consensus on the direction of impact of any house price determinant on house prices. There is less consensus however on the magnitude, the explanatory power, and the relative importance of the variables that drive changes in house prices (Algieri, 2013). A review of the literature on the dynamics of private housing prices reveals a myriad of variables that could be responsible for its dynamism (Adams and Füss, 2010; Baffoe-Bonnie, 1998; Bardhan *et al.*, 2003; Beltratti and Morana, 2010; Brooks and Tsolacos, 1999; Ho and Cuervo, 1999; Hou, 2010; Ng, 2002; Peng, 2002; Peng *et al.*, 2008; Tsatsaronis and Zhu, 2004; Tu, 2004; Xiao, 2007; Xiao and Tan, 2006). Most of these papers use a linear framework to examine this relationship albeit either in a singular or multi-country framework. These studies conclude that residential housing prices are consistently driven by several key variables encompassing interest rates, inflation, unemployment rates and economic growth. In general, the variables used for estimating changes in house prices are largely dependent on the type of modelling used. Girouard *et al.* (2006) have categorised the models into ones that are econometric in nature, models that are based on affordability indicators, and those which are asset-priced based.

By far, interest rates are the most oft-quoted macroeconomic explanatory variable as it measures the cost of financing a private residential property. Using a panel cointegration analysis consisting of 15 countries over a period of 30 years, Adams and Füss (2010) concluded that long-run increases in property prices are in response to increases in economic activity, construction costs, and a decrease in long-term interest rates. The results of the study by Bardhan *et al.* (2003) using Singapore housing data from 1990 to 2001 also confirms that real home loan rates are a key determinant of new private housing activity, amongst other factors such as stock equity wealth and changes to public housing market, with an increase in real mortgage rates resulting in decreased private housing activity.

Rising interest rates increases borrowing costs. This subsequently causes private residential property demand, and in turn prices, to decrease. Increases in mortgage servicing costs due to rising interest rates may result in growing number of mortgage defaults. It is especially acute in Singapore since all forms of mortgages originated are adjustable-rate mortgages (ARMs) (Ong *et al.*, 2007). A study on the Hong Kong property market prices by Peng (2002) incorporated time series dynamics by regressing real property prices against its own lags, a set of potential demand and supply variables, and their lags. It was found that lagged property prices, unemployment rate changes, real interest rates, changes in the rental index, changes to the public housing stock, and changes to demand of private housing were significant drivers of property prices. In particular, the study found that real interest rates were the main driver of property prices, with this variable alone accounting for 7 per cent of the total variation of real property prices. This is in comparison to unemployment rates that explained 6 per cent, and the rental index that explained about 5 per cent. Barber *et al.* (1997) found that U.K. house prices tend to co-move with unexpected inflation shocks and not anticipated inflation trends. Brooks and Tsolacos (1999) similarly indicate that the term structure of interest rates and unexpected changes in inflation also explain changes to the U.K. property market. Although nominal interest rates play a role in the formation of price appreciation expectations, real interest rates, as viewed by the homebuyer, has been argued to be the primary tool affecting the change in house price levels (Harris, 1989). As nominal interest rates are slow to incorporate changes in expectations, real rates tend to vary over time. Price expectations therefore play an important explanatory role on the dynamics of property prices.

Brunnermeier and Julliard (2007) conclude that inflation, rather than real interest rate changes causes changes in the price-rent ratio and a leading indicator of likely future economic downturns. This ‘money illusion’ causes incorrect discounting of future cash flows as most investors would normally use nominal discount rates rather than real discount rates. The Modigliani-Cohn hypothesis posits that investors suffer money illusion as they find it difficult in estimating long-term growth rates of cash flows. They therefore extrapolate historical nominal growth rates even in periods of changing inflation (Modigliani and Cohn, 1979). This implies that asset prices would be undervalued when inflation is high, and overvalued when inflation falls. Money illusion has not only been documented in stock markets (Campbell and Vuolteenaho, 2004; Cohen *et al.*, 2005; Ritter and Warr, 2002) but in housing markets as well (Brunnermeier and Julliard, 2007). Based on the money illusion literature, inflation is expected to have a negative relationship with house prices. This is counterintuitive with empirical research that house prices are an effective hedging tool against inflation in both in an emerging (Lee, 2014) and developed country context (Anari and Kolari, 2002). If house prices are a hedge against inflation, then the relationship should be positive.

Income has been found to be a significant determinant for property prices. Ho and Cuervo (1999) used the DiPasquale-Wheaton (1992) real estate market framework and found that apart from the prime lending rate, real GDP growth, which is a proxy for wealth, and the number of private housing starts have contemporaneous relationships with Singapore private residential property prices. Abraham and Hendershott (1996) documented that real income growth is one of the significant explanatory variables in property price appreciation across thirty U.S. metropolitan areas during the period of 1978-1992. This is because as rising incomes increases a household's ability to service mortgage payments on a property, this causes house prices to rise as a result of increased housing demand. Fraser *et al.* (2012) go further by decomposing the relationship between disposable income and house prices into temporary and permanent income shocks in three countries. Their results indicate that both temporary and permanent income shocks impact house prices in New Zealand and the U.K. with the latter having a greater impact. On the other hand, U.S. house prices show a muted response to both temporary and permanent shocks in disposable income which is in line with Gallin (2006). This indicates that house price-income relationship is country dependent.

Anecdotal evidence has also indicated that population growth is a key factor in explaining changes to private housing prices in Singapore. With a strong reliance on foreign workers to sustain its economic growth due to a declining fertility rate, Singapore's total population of residents and non-residents in 2020 is projected to rise to between 5.8 million to 6.0 million (O'Callaghan and Lim, 2013). This will put continued pressure on private housing market demand and result in prolonged increases in private housing prices. This pressure elicited by immigration affects private housing prices through the secondary market for private housing (Chia *et al.*, 2014). Population growth is posited to move positively with house prices as is immigration inflows. Empirical studies nevertheless have reported mixed results with some supportive of the positive relationship (Jud and Winkler, 2002; Otto, 2007; Terrones and Otrok, 2004) while others show no relationship between population growth and house prices (Leung, 2003; Peng *et al.*, 2008).

Singapore's housing market is rather unique as there is heavy government intervention through the provision of subsidized public housing, and a parallel private housing market. The interaction between both markets in the Singapore context has been studied extensively with the general conclusion that as incomes of Singaporeans increase, there is a tendency for Singaporeans to upgrade from public housing to private housing (Bardhan *et al.*, 2003; Chia *et al.*, 2014; Lum, 2002; Ong, 2000; Ong and Sing, 2002; Sing *et al.*, 2006; Yunus *et al.*, 2012). The extant literature stresses on the price transmission mechanism where resale prices in the secondary public housing market enables households to afford down payments in the more expensive non-subsidised private sector (Ortalo-Magné and Rady, 2006). However, there has been relatively scarce research conducted on the interactions between supply in the public housing market and demand in the private housing market in accordance to the economic theory of product substitution. We posit that public housing supply would have a negative effect on private housing prices.

The increasing competition among investors seeking good returns for their investments in a globalised setting has pushed the frontiers of investing in different asset classes, with diversification going beyond traditional stocks, bonds, money market instruments, and derivatives. Property investments have become an increasingly important asset class within a globalised investor's portfolio. Hoesli *et al.* (2004) found that adding real estate into a mixed-asset portfolio reduces a portfolio's risk by 10% to 20%. Investors are not only adding real estate to their portfolios as a risk reducing tool, but are also diversifying their investments in real estate not only domestically but internationally (Newell and Worzala, 1995). Foreign investors tend to invest aggressively in markets where the exchange rate is in their favour.

Therefore, exchange rates movements also have played an important role property price determination as exchange rates is one of the main factors influencing foreign investors' decision to enter real estate markets (Newell and Worzala, 1995). A favourable exchange rate for foreign investors entices them to purchase international property, subsequently pushing up the prices in the corresponding real estate markets, due to two reasons. First, it reduces the cost of investment at the onset. Second, the foreign investor realises investment returns if property prices escalate together with an appreciating domestic currency exchange rate. For example, the strengthening of the Japanese yen against the U.S. dollar after the 1985 Plaza Accord led to an influx of Japanese investors in the state of Hawaii which caused property prices to escalate (Miller *et al.*, 1988). The same positive relationship was also observed in cross-border property investments in the U.S. by Canadians citizens (Benson *et al.*, 1999). It can therefore be posited that a weakening domestic exchange rate may lead to a price rise in private house prices.

With regards to modelling techniques, there has been a slow but growing literature accounting for the property cycle when analysing the relationship between macroeconomic variables and private residential property price changes. Some of the first papers employing these techniques were Hall *et al.* (1997, 1999) who used a two-regime switching approach to develop a macroeconomic model for U.K. and Argentine house prices respectively. These papers identify two distinct regimes "boom" and "bust". This study adds a third regime referred to as "steady-state", as defined by Nneji *et al.* (2013). This state can be regarded as a neutral state where prices are neither inclined to move up or down for prolonged periods.

3. Data and Descriptive Statistics

The dataset consists of 136 quarterly observations from 1978Q1 to 2012Q1. The dependent variable used in this study is the private house price index obtained from Singapore's Urban Redevelopment Authority (URA). Based on the literature review, and considering the context of the Singapore private residential property market, the following key macroeconomic variables are considered in explaining private house price changes in Singapore: inflation rates, real effective exchange rates, real interest rates, population growth, public housing supply, and real disposable income growth.

Data for the explanatory variables was extracted from Datastream, unless otherwise stated. The explanatory variables are constructed as follows. The real Prime Lending Rate (PLR) is used as the proxy for interest rates. Inflation rates are computed as percentage changes in the consumer price index (CPI). Data for the population (POPN) is only available as an annual time series. As such, the data was interpolated using the quadratic match average method to obtain a quarterly time series. The data on real disposable income (1995 constant prices) was calculated based on Abeysinghe and Choy (2007).[2] Public housing supply (HDBS) is proxied by the number of completed public housing units, with this set of data obtained from various issues of the HDB Annual Report. As with the population data, the data on public housing supply is also recorded on an annual basis. Therefore, the quadratic matched average method was used again to obtain a quarterly time series. The data on Singapore's real effective exchange rate (EXCH) provided by Bruegel, a European based think-tank that constructed the dataset by employing the methodology

[2] Disposable income is calculated as GDP – taxes – government fees and charges – net Central Provident Fund (CPF) contributions. We thank the authors of the book for responding to our request for the updated disposable income data.

developed in Darvas (2012)[3]. For each of the dependent and explanatory variables, except for inflation, the growth rates from one quarter period to the next was computed and the corresponding summary statistics are depicted in Table 1.

From Table 1, it can be seen that average private house prices have increased by 1.65% per quarter or 6.76% per annum compounded. Private residential property prices have increased 25.5% in a single quarter during the boom periods and suffered a steep decline of 13.2% during crash periods. Interestingly, the price declines during crash periods have been less severe. In the second column, Singapore's inflation rate has been generally benign at 0.57% a quarter on average. The highest inflation on record is 3.76% recorded in the early 1980s. Growth in disposable income averaged 1.62% per quarter or 6.63% on an annualised compounded basis. Singapore's population has averagely grown 0.36% per quarter with the maximum recorded growth at 1.45% on a quarterly basis.

Table 1: Descriptive statistics

	ΔCPI	$\Delta EXCH$	$\Delta HDBS$	ΔDI	$\Delta POPN$	ΔHP	ΔPLR
Mean	0.568%	0.111%	-0.817%	1.619%	0.358%	1.649%	0.859%
Maximum	3.764%	4.233%	74.281%	12.723%	1.458%	25.499%	48.829%
Minimum	-0.998%	-7.126%	-40.755%	-10.312%	-2.887%	-13.209%	-37.898%
Skewness	1.137	-0.856	0.977	-0.323	-4.504	0.679	0.554
Kurtosis	2.823	2.105	4.141	1.990	36.135	2.144	0.770

Notes: CPI, EXCH, HDB, DI, POPN, HP and PLR denotes the consumer price index, real effective exchange rate (REER), HDB supply, disposable income, population, and private house prices, and prime lending rates respectively. The symbol "Δ" denotes the percentage changes in the series calculated as the first difference in logs. The data series for private house prices and prime lending rates are adjusted for inflation.

4. Methodology

4.1 Model Classification

In this paper, we apply a three-regime univariate Markov switching (MS) model due to Hamilton (1989, 1994), similar in spirit to Nneji *et al.* (2013). The existing literature, largely uses linear regression type models to examine the relationship between growth in house prices and other macroeconomic variables. In contrast, a MS model allows for dramatic breaks in the behaviour of house price growth by including the transition of regimes, or states, as an intrinsic property of the econometric model. The econometric model under study is then expressed as

$$\begin{aligned} HP_t = {} & \beta_{S_t,0} + \beta_{S_t,1}\Delta DI_{t-1} + \beta_{S_t,2}\Delta CPI_{t-1} + \beta_{S_t,3}\Delta PLR_{t-1} + \beta_{S_t,4}\Delta POPN_{t-1} \\ & + \beta_{S_t,5}\Delta HDBS_{t-1} + \beta_{S_t,6}\Delta EXCH_{t-1} + e_{S_t} \end{aligned} \quad (1)$$

where $e_{S_t} \sim N\left(0, \sigma_{S_t}^2\right)$, and S_t =1, 2 or 3[4]. The term S_t is the latent state variable which takes the value of either 1, 2 or 3, indicating the state or regime the house market is in. The $\beta_{S_t,i}$ coefficients, for i = 1 to 6, measure the change in the growth in house prices from a change in a macroeconomic variable of interest in model (1), whilst controlling for other macroeconomic variables. Unlike the linear regression model that assumes a constant effect of each of the independent variables on the dependent variable across all time periods, the MS model in (1) allows for the effect of each of the explanatory economic variables to

[3] The data on the Nominal Effective Exchange Rate (NEER) and Real Effective Exchange Rate (REER) were provided to us by Zsolt Darvas, senior research fellow at Bruegel, a European based think-tank.

[4] The variables in Equation (1) are percentage changes of the variables, computed as the first difference in logs. For example, ΔHP_t is computed as $logHP_t - logHP_{t-1}$, and is subsequently interpreted as the percentage change in house prices from one quarter to the next.

depend on the state the housing market is in. As with Nneji *et al.* (2013), the explanatory variables in model (1) are lagged by a time period of one quarter to allow for the delayed effect of changes in the economy on the housing market, and to also avoid a possible endogeneity problem that arises from feedback within the variables if the model in (1) had been contemporaneous in nature.

With reference to the three-regime MS model in (1), the term S_t could take on a value of 1, 2 or 3 depending on whether the housing market is in a boom, crash or steady state. This latent state variable is governed by a first order Markov chain with a constant transition probability matrix defined as:

$$P = \begin{bmatrix} \Pr(S_t = 1|S_{t-1} = 1) & \Pr(S_t = 2|S_{t-1} = 1) & \Pr(S_t = 3|S_{t-1} = 1) \\ \Pr(S_t = 1|S_{t-1} = 2) & \Pr(S_t = 2|S_{t-1} = 2) & \Pr(S_t = 3|S_{t-1} = 2) \\ \Pr(S_t = 1|S_{t-1} = 3) & \Pr(S_t = 2|S_{t-1} = 3) & \Pr(S_t = 3|S_{t-1} = 3) \end{bmatrix} = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix}, \quad (2)$$

where p_{ij} refers to the transition probabilities of the housing market in moving from state i in period t-1, to state j in period t. The Markovian nature of the probability matrix P specified in (2) assumes that the probability of a change in regime depends on the past only through the value of the most recent regime. The sum of each column in P is equal to one, since they represent full probabilities of the process for each state.

4.2 Model Estimation

The MS model in (1) is estimated via maximum likelihood, with the vector of parameters to be estimated denoted by $\theta = \left(\beta_{S_t,0},\ \beta_{S_t,1},\ \beta_{S_t,2},\ \beta_{S_t,3},\ \beta_{S_t,4},\ \beta_{S_t,5},\ \beta_{S_t,6}, \sigma^2_{S_t},\ p_{11},\ p_{22},\ p_{33}\right)'$. To construct the log-likelihood function for the model, we first consider the *conditional* likelihood function for state j given by $f(y_t|S_t = j,\ \Omega_{1:t-1};\theta)$, for $j = 1, 2, 3$, where $\Omega_{1:t-1} = (y_{t-1}, y_{t-2}, \dots,\ X_{t-1},\ X_{t-2}, \dots)$ represents all the past information up to time t-1, and θ is the vector of parameters. Note also that X_t is the vector of explanatory variables at time t in model (1). The full log-likelihood function of the model is then a weighted average of the likelihood function in each state, given by:

$$\ln L = \sum_{t=1}^{T} ln \sum_{j=1}^{3} f(y_t|S_t = j, \Omega_{1:t-1};\theta) Pr(S_t = j) \quad (3)$$

where the weights in (3) are given by the probabilities of the states, $Pr(S_t = j)$ for j = 1, 2, 3. However, these probabilities are unknown and therefore, the log-likelihood function in (3) cannot be applied directly. Instead, these probabilities have to be inferred via Hamilton's filter, which is used to calculate the filtered probabilities of each state based on the observation of new information.

Filtering refers to the determination of $Pr(S_t = j|\Omega_{1:t})$, which is the probability of the latent state, S_t, given $\Omega_{1:t}$, for each t = 1,2,…,T. The objective of filtering is to update knowledge of the system each time new information is observed. Therefore, filtering is a recursive procedure that is applied for each t, revising a filtered distribution by using new information, to produce the updated filtered distribution. Using Hamilton's filter, the estimates of $Pr(S_t = j)$ in (3) are available using the following iterative filtering algorithm:

1. Set arbitrary starting probabilities (t = 0) of each state $Pr(S_0 = j)$ for j = 1, 2, 3. One could simply set $Pr(S_0 = j)$ = 1/3, or estimate $Pr(S_0 = j)$ itself by maximum likelihood.

2. Set t = 1 and calculate the predictive probability of each state given information up to time t-1:

$$Pr(S_t = j|\Omega_{1:t-1}) = \sum_{i=1}^{3} p_{ij}\big(Pr(S_{t-1} = i|\Omega_{1:t-1})\big) \tag{4}$$

where p_{ij} are the transition probabilities from the probability matrix in (2).

3. Using the new information observed at time *t*, the predictive state probability in (4) then feeds into the calculation of the updated filtered state probability given by:

$$Pr(S_t = j|\Omega_{1:t}) = \frac{f(y_t|S_t=j,\Omega_{1:t-1};\theta)Pr(S_t=j|\Omega_{1:t-1})}{\sum_{j=1}^{3} f(y_t|S_t=j,\Omega_{1:t-1};\theta)Pr(S_t=j|\Omega_{1:t-1})} \tag{5}$$

As the error term in model (1) is assumed to be normally distributed, the conditional density in the numerator of (5) is represented as:

$$f(y_t|S_t = j, \Omega_{1:t-1};\theta) = \frac{1}{\sqrt{2\pi\sigma_j^2}} exp\left\{-\frac{\left(y_t - X'_{t-1}\beta_j\right)^2}{2\sigma_j^2}\right\} \tag{6}$$

4. Set t = t+1 and repeat steps 2-3 until t = T. This would provide a set of filtered probabilities for each state, from t = 1 to t = T.

By observing the denominator in (5), we note that this filtering process, in revising each state probability, produces the probabilities needed for calculating the log-likelihood function of the model as a by-product. The log-likelihood function of the MS model in (1) is subsequently represented as

$$\ln L = \sum_{t=1}^{T} ln \sum_{j=1}^{3} f(y_t|S_t = j, \Omega_{1:t-1};\theta)Pr(S_t = j|\Omega_{1:t-1}) \tag{7}$$

Estimation of the vector of parameters, θ, is then done by maximizing the log-likelihood function in (7).

In addition to the computing of the filtered probabilities, we also compute the smoothed probabilities - probabilities of what state the housing market was in at a particular time period, *t*, given *all* the observations and information up to a later time period *T*. These smoothed probabilities are computed using the algorithm by Kim (1994). These probabilities are of interest because by inferring about the states using the whole information set up to the last observation at time *T*, an insightful understanding of the housing market can be obtained.

5. Results

We first analyse the relationship between changes in the private residential property price index and the various identified macroeconomic variables using normal ordinary least squares (OLS) estimation procedure. The results are shown in Table 2.

The results of the linear single state model indicate that only lagged disposable income growth and lagged inflation rates are significant at the 1 per cent and 5 per cent level respectively. Disposable income growth has a positive beta, which implies an increase an increase in disposable income growth is expected to have a positive effect on private residential property prices. Lagged inflation rates are also positively related to private residential property prices. This result might be an indication that Singapore property prices have potential hedging characteristics towards inflationary pressures. Previous studies have shown that real estate, whether commercial or private dwellings have potential hedging characteristics especially in relation to unexpected inflation (Barber *et al.*, 1997; Hoesli *et al.*, 1997). The other macroeconomic variables are not statistically significant.

Table 2: Output from linear regression model of Eq. (1) for a single regime using OLS estimation procedure.

	Constant	ΔCPI_{t-1}	ΔPLR_{t-1}	$\Delta POPN_{t-1}$	ΔDI_{t-1}	$\Delta EXCH_{t-1}$	$\Delta HDBS_{t-1}$
β	0.006	1.563**	0.0214	-2.085	0.411***	0.453	0.010
	(0.463)	(0.039)	(0.515)	(0.103)	(0.003)	(0.138)	(0.736)

Notes: This time series regression analysis is performed on the whole sample period from 1987-2012. The dependent variable is the quarterly percentage change in private residential property prices and the independent variables are one quarter lag percentage change in inflation rates (ΔCPI), prime lending rate (ΔPLR), population (ΔPOPN), disposable income (ΔDI), real effective exchange rates (ΔEXCH), and HDB housing completion (HDBS). These percentage changes are computed as the first difference in logs. The figures in parentheses are the p-values and * indicates significance at 10%, ** 5%, and *** 1% respectively.

The results raises questions whether the using a linear approach can be considered to be an optimum solution to address our research questions. We conjecture that the sensitivity of private residential property prices to economic changes may differ between regimes. There however should be some statistical basis for choosing the appropriate number of regimes. Therefore, we compared the number of regimes to be incorporated in our modelling of the private residential property prices based on observations of the Akaike information criteria (AIC) for one, two, three and four-regimes of the MS model. A two-state model would be categorised as having only "boom" and "busts" whereas a four-regime model identifies the regimes as a cycle of "crash", "boom", "slow growth" and "recovery" (Guidolin and Timmermann, 2007; Rydén *et al.*, 1998). Our analysis indicates that the three-regime Markov switching model has the smallest AIC values.

Before estimating the regime-switching betas, it is important also to analyse and discuss the smoothed probabilities of the Singapore private property market being in any one of these regimes. The smooth probabilities provide an indication on which regime the property market is in at each point of time from observations of the complete dataset. As stated earlier, the smooth probabilities are dependent on the estimated transition probability matrix that provides information on the probability of switching from one state at time $t-1$ to t provided as per Eq. (2). The estimated transition probability matrix for the Singapore private property market is shown in Eq. (8).

$$P = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix} = \begin{bmatrix} 0.809 & 0.077 & 0.091 \\ 0.159 & 0.849 & 0.084 \\ 0.032 & 0.074 & 0.825 \end{bmatrix} \tag{8}$$

We define the regimes as p_1 as the crash regime, p_2, the steady-state regime and lastly p_3 as the boom regime. As seen from Eq. (8), the probability of the private residential property market remaining in steady-state given that the private residential property market was in a steady-state in the previous period is 84.9 per cent. This is the most prevalent regime for the sample period. There is an 8.4 per cent probability of moving from a steady-state regime to a boom regime while a 15.9 per cent chance of a crash occurring if the previous period was a steady-state regime. The crash regime has the least persistence where there is an 80.9 per cent probability of remaining in the crash state should the previous period also be in a crash state. From the transitional probabilities, we can easily calculate the duration of each state with the following equation:

$$ED = {}^{1}/_{(1-p_{ii})} \tag{9}$$

The expected duration of being in the steady-state, boom and crash regimes are 7, 6, and 5 quarters respectively. The cycles are much shorter than reported by Nneji *et al.* (2013). It is expected then that a property boom extends for 1.5 years whereas a property bust lasts for 1.25 years. This is contrast with Nneji *et al.* (2013) where the bust periods are much more prolonged but are more in line with the bubble periods reported by Phillips and Yu (2011).

Fig. 1 shows that for much of the sample, the dominant state the private residential real estate market is in is the steady-state. In observing the data plots, private residential property prices tend to follow the business cycles of the Singapore economy in general. The property boom in the late 1980s coincided with sustained economic growth after the second oil shock. Property prices suffered a prolonged decline mirroring the decline in GDP growth culminating in the mid-1980s recession (Choy, 2009). Policymakers also had significant influence on the movements of private residential property prices. For example, to lift the market from the doldrums as a result of the mid-1980s recession, in November 1988, the Central Provident Fund (CPF) (compulsory pension fund that all working Singaporeans must contribute to) raised the total CPF withdrawal for the purchase of private housing to 100% of the value of the property. This resulted in property prices rising until the 1990 Gulf War and thereafter declining.[5]

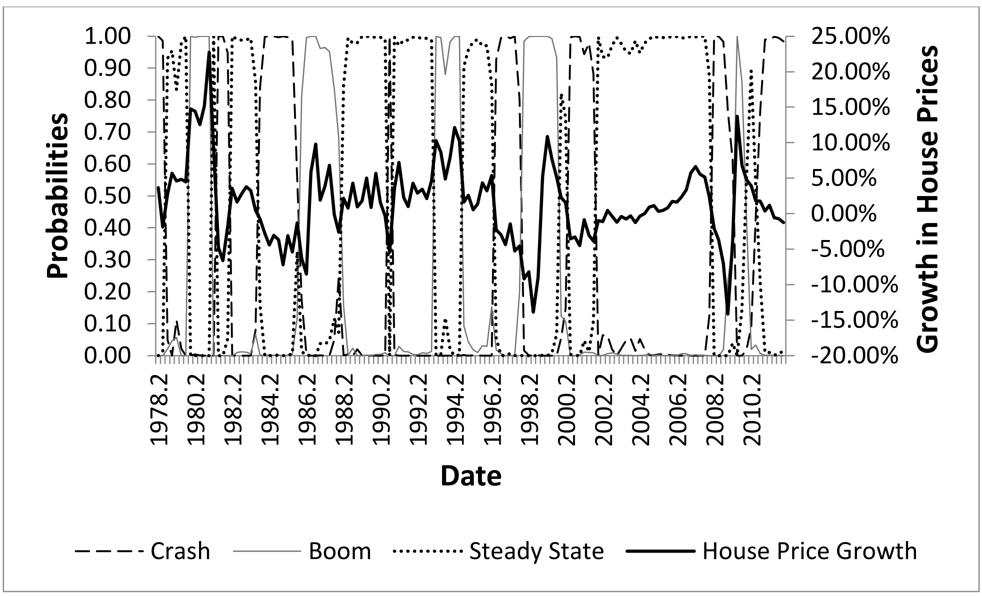

Figure 1: Private residential property price dynamics and regimes

The most notable private residential property price decline occurred during the 1997 Asian financial crisis. However, prices started to fall as early as 1996Q1 due to the anti-speculative measures taken by the government to curb speculation. In the most recent periods, price booms have been documented from May 2007 till throughout 2008 culminating in a crash related to the 2008 Global Financial Crisis (Phillips and Yu, 2011).

The results of the estimated MS model are shown in Table 3. It provides a detailed view of how the six economic variables influence the growth in private residential property prices in the three regimes. We can see from Table 3 that there are clear differences in the signs of

[5] For a comprehensive view of how private residential property markets are affected by government policies, refer to Phang and Wong, 1997.

the coefficients and their significance depending on the regime the private residential property market is in. In the steady state and boom regimes, lagged inflation plays a significant role in explaining the movements of private residential property prices. A positive coefficient means that private residential property can be used as a hedging tool against increase in inflation. These results are similar to the linear model.

Table 3: Markov switching model output.

Regime	Constant	ΔCPI_{t-1}	ΔPLR_{t-1}	$\Delta POPN_{t-1}$	ΔDI_{t-1}	$\Delta EXCH_{t-1}$	$\Delta HDBS_{t-1}$
Steady state	0.009*	1.616***	0.029	1.829**	-0.071	0.281	0.043***
	(0.072)	(0.000)	(0.108)	(0.026)	(0.446)	(0.208)	(0.000)
Boom	-0.010	10.411***	-0.048	3.741***	0.755***	0.918**	-0.0246***
	(0.433)	(0.000)	(0.396)	(0.007)	(0.000)	(0.015)	(0.001)
Crash	0.026**	-0.192	0.001	-14.677***	0.080	0.208	-0.013
	(0.023)	(0.671)	(0.739)	(0.000)	(0.335)	(0.449)	(0.738)

Notes: The regression analysis encompasses the full sample period between 1978Q2 to 2012Q1. The dependent variable is the quarterly percentage change in private residential property prices and the independent variables are one quarter lag percentage change in inflation rates (ΔCPI), prime lending rate (ΔPLR), population (ΔPOPN), disposable income (ΔDI), real effective exchange rates (ΔEXCH), and HDB housing completion (HDBS). These percentage changes are computed as the first difference in logs. The figures in parentheses are the p-values and * indicates significance at 10%, ** 5%, and *** 1% respectively.

Lagged disposable income growth is only significant in the boom state. Unlike the linear model where lagged disposable income growth was statistically significant, the MS model depicts that lagged disposable income growth positively plays no significant role in growth of private residential property prices in the crash and steady state respectively. This is consistent with prior studies in other developed markets indicating that the income-price elasticity is neither stable nor constant over an extended period of time (Fraser *et al.*, 2012; Malpezzi, 1999; Tse and Raftery, 1999).

An interesting finding is the relationship between population growth and private residential property prices. There are clear differences in the sign of the relationship. In a crash regime, it is a significant negative relationship whereas in the boom and steady state, the relationship is positive. In the linear model, population growth is not statistically significant. We conjecture that the negative relationship seen in the crash regime could be due to periods consistent with negative growth in the Singaporean economy resulting in a slowdown in migration affecting population growth. The negative relationship may also be due to substitution effect between public and private housing during the crash period which would dampen private house prices which could explain the significant negative relationship between population growth and changes in private housing prices. In the boom state however, the results are consistent with the anecdotal argument that population growth puts pressure on demand for private residential properties and thus exacerbates prices (Glindro *et al.*, 2008).

Changes in the prime lending rate surprisingly have no significant effect on private residential property price changes. This contradicts earlier literature on the interest rate effects towards private residential property prices (Bardhan *et al.*, 2003; Tu, 2004). We offer two explanations for this result. Firstly, since 1981, the Monetary Authority of Singapore (MAS) monetary policy has centred on the management of the exchange rate with the primary objective to promote price stability as a sound basis for sustainable economic growth. This choice of the exchange rate as an intermediate target of monetary policy implies that MAS cedes control over domestic rates.

Neither change in money supply nor factors' affecting the demand for money affect domestic interest rates. Instead changes in U.S. interest rates and/or market expectations of future movements in the exchange rate have significant explanatory value on the domestic interbank rate (Monetary Authority of Singapore., 1999). Secondly, most Singaporeans contribute to the Central Provident Fund (CPF). From 1981 onwards, CPF members were allowed to use up to 80% of their CPF ordinary account savings for payment of a housing loan for the purchase of private residential property. As CPF contributions are mandatory, CPF members would be less sensitive towards interest rate changes since it is actually not an out of pocket discretionary income commitment but rather from retirement savings.

In summary, the results clearly show that the MS model is much more superior in providing a wealth of information on the explanatory variables relationship with private residential property prices as compared to the static linear model. It also can provide avenues for further analysis into policy measures that can be undertaken by the Singaporean government to initiate regime shifts.

5.1 Suggestions for Future Research

The proposed model above has used several macroeconomic variables to explain price changes in Singapore's private residential market. Several important variables have been omitted with could explain changes in prices in the private residential market. The incorporation of these variables within the Markov switching framework could enhance our understanding of private residential price behaviour. Among these are supply variables such as private housing starts and increased activity in the release of available land by the Singaporean government for private housing. The other variable of note would be a proxy variable for Singaporean government policies as there is considerable government intervention in the housing market. Further to this, the impact of low birth rates in Singapore has led to an increase in the expatriate community which would lead to increase foreign investment interest in the Singapore private residential market. However, data on foreign investment in the private residential market is of limited time length and incorporating it would preclude us from using the Markov-switching framework. We defer the incorporation of these variables in the Markov switching framework for future research.

6. Conclusion

This paper analyses the impact of various lagged changes in macroeconomic variables on private residential house price growth in Singapore using a three-regime Markov-Switching methodology introduced by Nneji *et al.* (2013) to define periods of economic cycles. The method was found to be superior to the single regime linear regression framework predominantly used in the extant literature. The results identify lagged inflation, lagged disposal income growth, and lagged population growth as significant explanatory variables of private residential house price growth especially in the boom and steady state regimes. In using a three-regime analysis to determine explanatory variables in relation to house growth, it could improve the ability of the Singaporean government to have specific policy measures targeting the various significant macroeconomic variables when house prices are in a specific regime.

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